1. Data Acquisition: Data Collection/Ground Based (in situ) Monitoring

Suggested technology priorities:

- **Expanded collection of critical data;**
- **Improved quality and consistency of data collection standards across agencies;**
- **Improved data sharing and collection of data currently unavailable due to lack of regulation or user cooperation; and**
- **More widespread development and use of robust, cost effective sensors.**

The state needs a more robust and sustainable population of in situ data collection technologies capable of collecting the minimum range of data required to effectively plan and operate California's water system. A patchwork arrangement of data collection systems funded and maintained by federal, state, local, and private agencies and organizations has led to a lack of comprehensive coverage and sensors subject to the vagaries of budgetary and maintenance issues too varied and numerous for most to keep track of.

In addition, the wide range of organizations collecting data currently employs different instrumentation, different standards for collection (both in terms of what is collected and how often it is collected), and different means of storing and distributing the data. This makes integrating and using data from different regions, and even different systems within the same region (e.g. rainfall, snowpack, and aquifer levels) difficult. Upgrading the quality and consistency of the data being collected could be a cost-effective way to facilitate integration and management of data collected by different networks, perhaps via a governmental entity dedicated to environmental data quality. Such an entity could provide technical leadership for environmental data collection, ensuring that aggregated data are useful for decision-making.

Some data collection systems are currently closed, in that private industrial parties collect information necessary for their own operation (e.g. groundwater levels and certain water quality constituents). This seriously impedes the ability of state and local water management to gain a truly systematic overview of critical data in these regions. Absent a regulatory mandate to share these data, these parties decline to do so because of various concerns. This situation requires a thorough investigation to determine the appropriate application of technology that provides resolution.

California could also benefit from expanding existing small-scale technologies such as soil moisture sensors, web-based tools, instrumentation for real-time assessment of groundwater recharge rates by location, development of isotropic tracers to assess groundwater age, and DNA analysis for monitoring invasive aquatic species, among other technologies.

Survey Overview: Data Acquisition Technologies (In-Situ/Ground-Based Sensors)

Currently possible, likely significant impact	• Office of environmental data quality - to establish consistent standards • Unified web portal for existing data • Small visual/hyperspectral sensors installed near water to measure water turbidity and chlorophyll content
Currently possible, likely limited impact	• Development of isotopic tracers to assess groundwater age, transport, and contaminants
Promising, likely significant impact	• Instruments to easily assess in situ nitrates and other constituents in groundwater
Promising, likely limited impact	• Phosphorous sensors • Noble gas sensors (to track groundwater recharge) • DNA analysis for monitoring invasive aquatic species

2. Data Acquisition: Data Collection/Remote Sensing

Suggested technology priorities:

- **Increased investment in the development and deployment of remote sensors;**
- **Preparing California to exploit information derived from existing and future earth observing missions; and**
- **Convening individuals from National Laboratories in California together with experts from academia, government and the private sector to chart the course for necessary water related research that can best be performed by the National Laboratories (DOD, DOE, NASA).**

As with in situ sensors, California needs a more robust and sustainable population of relatively inexpensive remote sensors; one example cited is a visual sensor no more powerful than an iPhone, capable of analyzing water turbidity and chlorophyll concentration, which could be easily installed on the underside of bridges and on buildings near water.

The state needs to be prepared to better integrate information from NASA as well. The Landsat satellites are already collecting valuable information on snowpack, and scientists at JPL have been working over the past decade to develop new algorithms to take better advantage of data already being collected. The NASA Surface Water Ocean Topography (SWOT) mission - scheduled to launch in 2019 - offers even greater potential for regular measurements of surface water levels throughout the state. The state should invest in developing systems capable of using these data, and in airborne remote sensors onboard drones to complement the satellite data, providing greater resolution and/or compensating for cloud cover as needed.

Partnerships between NASA labs and individual states will be a major component to facilitate making better use of satellite data. For example, targeted airborne/drone sensors could be operated in cooperation with NASA and/or private industry, making flexible, periodic availability of these resources financially feasible for the state. California needs to bring together experts from the National Laboratories and its academic, government and private sectors to best determine how to move forward.

Survey Overview: Data Acquisition Technologies (Remote Sensing)

Currently possible, likely significant impact	• New algorithms to take advantage of data from existing satellite platforms
Currently possible, likely limited impact	• Airborne drones to provide targeted data to complement satellite data on snowpack • Microgravity monitoring of water storage changes • Expanded network of inexpensive, local remote sensors
Promising, likely significant impact	• Partnerships between NASA, state and private sectors • Integrated modeling framework that combines data from remote and onsite sensors • SWOT mission
Promising, likely limited impact	•

3. Data Management (Access To and Use of Data and Modeling)

Suggested technology priorities:

- **Better systems for sharing data across agencies;**
- **Better management/applications of data already being collected;**
- **Developing consistent standards for data collection and dissemination;**
- **Making more real-time data available, especially where regulation and enforcement are now lacking (e.g., measuring and reporting groundwater discharge, recharge and aquifer water quality);**
- **Investment in models capable of integrating data from remote and onsite sensor systems;**
- **Improved modeling and decision making software; and**
- **New standards for verifying models against actual in situ data.**

Currently different water agencies at the federal, state and local level each employ their own data collection and database management systems. There are web portals and multi-agency resources intended to bridge these systems, but they are universally described as incomplete and/or works in progress. To effectively manage data from multiple governmental and other sources the California Environmental Data Exchange Network (CEDEN) must be adequately funded to perform its mission and achieve its goals, which include (http://www.ceden.org):

- Incorporating diverse data sources into a standardized, integrated data sharing network;
- Providing direct public access to monitoring data in an easily downloadable form; and
- Supporting question-driven assessments available via the California Water Quality Monitoring Council's My Water Quality web portals at: *www.cawaterquality.net*.

Additionally, real-time data coverage across the state is inconsistent. It is difficult for regional water management systems to assess the value or reliability of data collected elsewhere and funding for the collection of data and related information is often the first to be routinely cut at every level of government when budgets are tight (e.g., the current sequester has led the USGS to close approximately 375 stream gages across the country).

Moreover differences in collection methods and processing time mean that real-time information is often simply unavailable. Suggested remedies included implementation of an advanced metering infrastructure similar to the smart-meters being employed by California based independently operating utilities (IOUs).

Better models would be much more useful in addressing integrated water management objectives if provided with additional data. Expanding these models and making them more responsive in real-time could benefit from the use of high performance computing resources, which could both provide better real-time analysis and run a variety of potential scenarios in advance.

Survey Overview: Data Management (Access To and Use of Data and Modeling)

Currently possible, likely widespread impact	• Web-based information exchange systems using distributed data models allowing different entities to maintain and share data • Better access to real-time data by the public
Currently possible, likely limited impact	• Wider use of simulation programs such as CalSim 2, CalLite and Plexos (Power Benefits Model)
Promising, likely widespread impact	• High performance computing resources for management and understanding of large scale, coupled environmental water and regional climate systems • Advanced metering infrastructure and data communication tools to communicate real time water usage
Promising, likely limited impact	•

4. Water Treatment Technologies: Membrane Filtration Based

Suggested technology priorities:

- **Adaptable control systems (smart control systems), capable of automatically achieving predetermined operation goals in the face of variable water quality;**
- **Further development of more robust general-purpose membranes, with an emphasis on lower cost and lower energy use;**
- **Further development of energy recovery technology; and**
- **Significantly broadened deployment of desalination technologies, including the streamlining of the regulatory process and the incorporation of experience in other venues than California.**

There currently is no such thing as a 'universal' membrane treatment system. The need for more adaptable control systems is essential, particularly for the treatment of brackish and re-used water where contaminants may vary significantly in type and concentration. Such control systems would also significantly benefit from better information about the water being treated; at times, respondents asserted, sensor systems at some treatment facilities do not even provide reliable pH measurements.

In addition to improving control systems, development of more robust general-purpose membranes would facilitate treatment plant adaptability and lower costs. An emphasis on lowering membrane system energy demands - currently a significant factor in their cost - is also essential.

Lowering energy system demands in large part includes recovering energy from the filtration process. The use of renewable energy in local treatment facilities could also reduce overall energy demands on the state.

Overall, application of membrane treatment technologies in California, and the U.S. in general, lag significantly behind other areas of the world such as Israel, countries in the Arabian Gulf and Mediterranean, and Australia, which face even more restricted water resources than California. Israel, for example, recycles over 80% of its water, compared to just 6% for California. In part, the application of membrane filtration in California could be refined now based on research conducted for plants in operation in the United States outside of California and overseas.

Survey Overview: Water Treatment Technologies (Membrane Filtration Based)

Currently possible, likely significant impact	• More significant use of sensors to assess groundwater quality • Use of data from other states and countries to assess impacts of the use of membrane technologies
Currently possible, likely limited impact	• Increased use of renewable energy in membrane treatment
Promising, likely significant impact	• Development of more robust filters, possibly using hybrid desalination processes such as forward osmosis / reverse osmosis, forward osmosis/nanofiltration, etc. • Development of "smart control systems" to automatically adapt membrane filtration systems to changing water quality and demand • Collection of groundwater quality data from oil companies and other private operators
Promising, likely limited impact	• Real-time public display of sensor data on key contaminants to increase public confidence

5. Water Treatment: Physical, Biological and Chemical (non-membrane based technologies)

Suggested technology priorities:

- **Development and deployment of technologies focused on wastewater cleanup for recycling;**
- **Technology development to support the increased use of distributed water and wastewater treatment systems;**
- **Narrowing the gap between what's feasible in the lab and what's approved for use in the field; and**
- **Deployment of engineered, constructed wetlands technology.**

Effective wastewater recycling is challenging because it requires multiple treatment systems operating in conjunction with each other. The development of improved biological filtration and better use of local, low-energy treatment options make this potentially more feasible.

Distributed, in-situ groundwater remediation is an approach that can target existing technologies more effectively to the needs of regional water systems, an approach which is being used to some extent already. Research programs such as ReNUWIt (Stanford University) and PIRE (UC Irvine) are also examining low-energy options for treating wastewater in a more distributed system.

Laboratory techniques for chemical water treatment can be years ahead of what is approved for in the field, due to a lengthy and at times onerous regulatory approval process; streamlining this process could lead to immediate or near-term application of more sophisticated treatment and analysis technologies, such as fluorescent scans (currently used by oceanographers). The application of nanotechnology to help prevent fouling of membranes is one area that could use expansion.

Perhaps the most effective place for the state to invest in chemical/biological treatment today is in the use of constructed wetlands. Properly engineered, these systems rely on solar power as an energy source and can be effective in removing targeted pharmaceuticals from the water supply.

Survey Overview: Water Treatment: Physical, Biological and Chemical (non-membrane based technologies)

Currently possible, likely significant impact	• Constructed wetlands, optimized for specific treatment outcomes • More reliable basic sensors
Currently possible, likely limited impact	• Scanning techniques developed by oceanographic researchers such as fluorescent scans
Promising, likely significant impact	• Distributed, low-energy treatment options applied at local level • Application of nanotechnology to enhance and bolster membrane treatments
Promising, likely limited impact	• Improved biological filtration, e.g. targeted removal of selenium in agricultural runoff

6. Watershed Management (Including Groundwater Recharge)

Suggested technology priorities:

- **Ability to combine and utilize applicable models more effectively in recognition of climate change impacts on watersheds;**
- **Improved data collection for surface water and groundwater basin descriptive parameters, including water runoff and storage as a function of time throughout the basin; and**
- **Expanded use of flood plains and other sites having good recharge potential for groundwater recharge.**

There are not enough models that allow effective evaluation of trade-offs between different aspects of total watershed management including economic considerations. This is partially due to the 'siloed' approach to data collection and management currently utilized by the state. In combining a wider range of data into more complex models (including NOAA data), high-performance computing platforms could be used in advance to work on a range of possible scenarios. In addition, work needs to be done on translating these data/modeling/academic exercises to action on the ground. No technological innovation or watershed management approach will be adopted unless researchers can take them out in the field and convince stakeholders to buy into them.

Models are only as good as the data upon which they rely, and there is significant variability in groundwater monitoring up and down the state, ranging from 'very intense' to 'zero.' Improved and more consistent data collection would be an essential component to more effective watershed management.

Better data collection and models would also facilitate the expansion of more effective groundwater recharge techniques, for example, the wider use of flood plains for groundwater recharge.

Survey Overview: Watershed Management (Including Groundwater Recharge)

Currently possible, likely significant impact	• Restoration and expansion of forest and streamgaging stations • Better linking of NOAA data with data on the ground
Currently possible, likely limited impact	• Advance running of specific scenarios involving complex models using high-performance computing platforms
Promising, likely significant impact	• More complex and integrated models combining data from wider range of sources • Greater use of flood plains for groundwater recharge (possibly integrated with more storage to feed flood plains) • Better outreach to stakeholders using technology
Promising, likely limited impact	• Partnerships with private sector companies for local, real-time monitoring networks

7. Agricultural Water Use Efficiency

Suggested technology priorities:

- **Widespread adoption of water measurement and soil moisture sensing technologies;**
- **Selecting and installing high efficiency water distribution systems, providing necessary maintenance, and utilizing proper irrigation scheduling methods;**
- **Adoption of one or more technologies for water management, including remote sensing, weather based, and/or crop/soil based technologies;**
- **Development of cost-effective information management and controller technology for managing drip and micro-sprinkler line pressures throughout fields with diverse soil types;**
- **Using agricultural water and land whenever possible to provide environmental benefits (e.g. flooded rice ground to provide seasonal wetlands for migratory birds and reproduction habitat for fish);**
- **Identification of multiple use opportunities for water supplies (e.g. water exchanges between agricultural and urban users);**
- **Improving water use efficiency with the adoption of pressurized irrigation systems; and**
- **Fully understanding third-party impacts before implementing any large-scale changes in agricultural practices.**

In situ sensor technologies are used to some extent, but have been limited by cost and lack of incentive. More widespread use of water measurement and soil moisture technologies is called for.

Better and more comprehensive data would facilitate implementation of high efficiency water distribution systems, capable of more effective and targeted irrigation.

A number of technologies exist to provide improved water management, including both regular and high-efficiency systems, but that their adoption is hindered by a full lack of understanding the cost/benefits of adoption. Making on-site soil moisture data available to farmers, in conjunction with effective use of remote sensing data on soil moisture and crop coverage, could help make the cost/benefits more apparent. Satellite monitoring of crop health, soil moisture, and cover, if integrated with reliable on-site sensor data, would also be useful in providing more accurate models for tracking crop water needs and scheduling irrigations.

The adoption of improved water distribution and management technologies for irrigated agriculture has increased due to favorable yields and increasing water costs. The new driver for accelerating adoption will be to protect the groundwater from contaminants by regulators.

Finally, the economics of agricultural crops will ultimately determine future cropping patterns. As long as the grower is entirely responsible for the risk and reward of those decisions, higher value crops (and in many cases higher water consumptive) will continue to be selected, but perhaps on less acreage as water becomes the limiting factor. Consideration should be given to the possible use of incentive based regulation in this area. Because of the economic impacts of change, the full impact of major shifts in agricultural practices should be understood to the greatest extent possible before implementing them.

Survey Overview: Agricultural Water Use Efficiency

Currently possible, likely significant impact	• Improve on-farm water measurement and soil water sensing, that will lead to improved irrigation scheduling and management. • Growers need an active program to evaluate and upgrade their current irrigation systems that do not meet current distribution Uniformity standards
Currently possible, likely limited impact	• Identify opportunities to improve crop water use efficiencies
Promising, likely significant impact	• Remote sensing of crop cover and crop coefficient; combining satellite data with daily weather data, soils, and irrigation to help refine crop water balance
Promising, likely limited impact	• Crop switching to lower water demand.

8. Urban Water Use Efficiency

Suggested technology priorities:

- **Enhanced metering infrastructure;**
- **Greater deployment of lower water use technologies;**
- **Greater reuse and more reliance on partially treated water for non-potable purposes;**
- **Enhanced leak detection and repair programs;**
- **Greater use of incentive based pricing to encourage more water conservation; and**
- **Greater use of low water intensity landscaping, possibly reinforced with stricter codes/regulation.**

Better real-time data on water use could be used to improve water use by consumers, as well as enhance the state's ability to assess real-time demand, improving accuracy and accountability for required Urban Water Demand Plans. Better metering would also help the development of improved high-resolution flood models, which could facilitate urban planning.

Better data on water use would also help expand deployment of lower water use technologies, such as low-flow toilets, which are currently effective and offer significant water savings but are not as widely used due in part to cost and in part to public perceptions based on performance issues in early generation models.

The expanded use of partially treated or "gray" water is also an important component of improving urban water use efficiency. Again, this depends upon education and better integration of treatment and data systems.

Leak detection and repair is a crucial component of urban water management, and this depends upon reliable data. Municipalities facing tight budgets may not commit properly to repair and maintenance efforts unless the true economic scope of leak loss is made readily apparent.

Considerably more could be done to encourage water conservation through financial incentives. These will be easier to calculate and communicate with better real-time data as indicated above.

In addition, many cities could make greater strides in requiring more low water intensity landscaping.

Survey Overview: Urban Water Use Efficiency

Currently possible, likely significant impact	• Improved metering infrastructure, e.g. wireless smart meters • More widespread use of lower water use technologies, such as low-flow toilets
Currently possible, likely limited impact	• Financial incentives for greater water conservation • Expanded use of "gray" water
Promising, likely significant impact	• Improved high-resolution flood models parameterized with LIDAR and data offer greater understanding of urban flood risks and have the ability to improve urban planning and emergency management • Better leak detection, more aggressive repair programs
Promising, likely limited impact	•

9. Water-Energy Nexus

Suggested technology priorities:

- **Greater use of smart grid technologies, especially to increase use of renewable energy sources;**
- **Minimizing unnecessary energy dissipation at point of use;**
- **Implementation of energy harvesting technology where feasible; and**
- **Increased use of technologies to improve energy efficiency for water treatment and transport processes.**

Just as for watershed management and urban and agricultural efficiency, the need for more and better data, obtained and managed in real-time, and for models to use the data constructively are key elements in managing water and energy. Smart grid technologies have already been deployed to facilitate management of the state's electric power, and similar technologies could be used to bring the water system in line, allowing more effective management of both.

Better data would help identify unnecessary energy dissipation at point of use, allowing for the development of strategies (technological and/or regulatory) to minimize this.

Certain facilities, such as submerged seawater desalination plants, could also be designed to produce renewable emissions-free power. Energy recovery is also possible from wastewater.

An increased use of technologies to improve energy efficiency in all applications is an essential component of better integrated water/energy management. Energy use is a significant component of the overall cost of most water treatment and efficiency systems, and a barrier to implementation of new technologies.

Survey Overview: Water-Energy Nexus

Currently possible, likely significant impact	• Smart grid technologies for water and energy conservation and management. In particular greater utilization of automatic meter reading and advanced meter infrastructures, in concert with power providers
Currently possible, likely limited impact	• Use of renewable energy for water treatment and transport processes
Promising, likely significant impact	• Integrated models for management and understanding of large-scale, coupled water and regional climate systems and energy supply
Promising, likely limited impact	• Developing anaerobic processes to facilitate energy recovery from wastewater